Proceedings of the DIS'2004, Štrbské Pleso, Slovakia

DIS: A PERSPECTIVE

A.D. MARTIN
Institute for Particle Physics Phenomenology, Durham University, DH1 3LE, UK

This talk is dedicated to the memory of Jan Kwieciński.

1 Introduction

The summary talks of the individual Working Groups have covered a vast range of information presented at DIS 2004. Even if it were possible, to attempt to summarize these excellent summaries would be unwise. Rather this talk gives, I hope, a general perspective of some of the present issues in DIS. The choice of topics betrays my personal interest, and I apologize for the many interesting DIS areas that I omit. I have included some of the slides that were shown in the talk, since it seems a succinct way of conveying some of the current ideas. The references are extremely patchy and are not at all representative – they are used mainly to assist the physics discussion and not to give credit – again I must apologize for the many omissions.

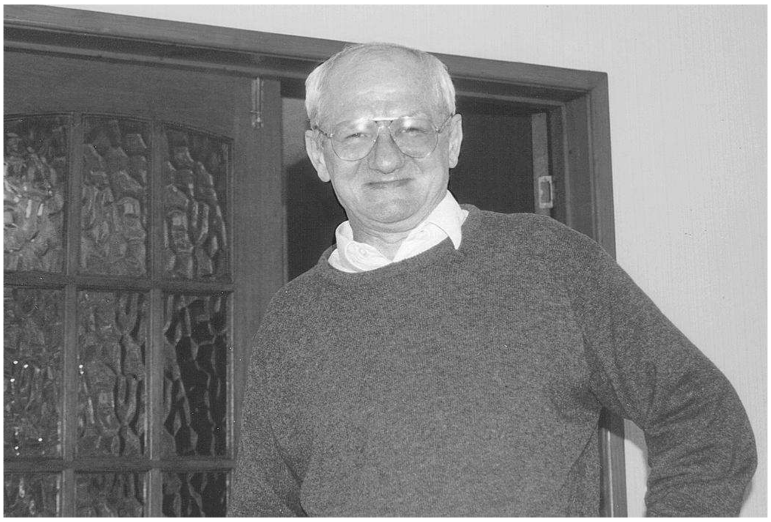

Figure 1. Jan Kwieciński (1938-2003): ... absolutely the kindest man I have ever met in my whole life... a quote from the CERN Courier of Jan-Feb 2004. Jan was an active participant, and speaker, at this series of DIS workshops. He built up an active research group in Krakow, about 100 miles North of here. Indeed three of his protégés, Krzysztof Golec-Biernat, Leszek Motyka and Anna Stasto, have made significant contributions to this meeting.

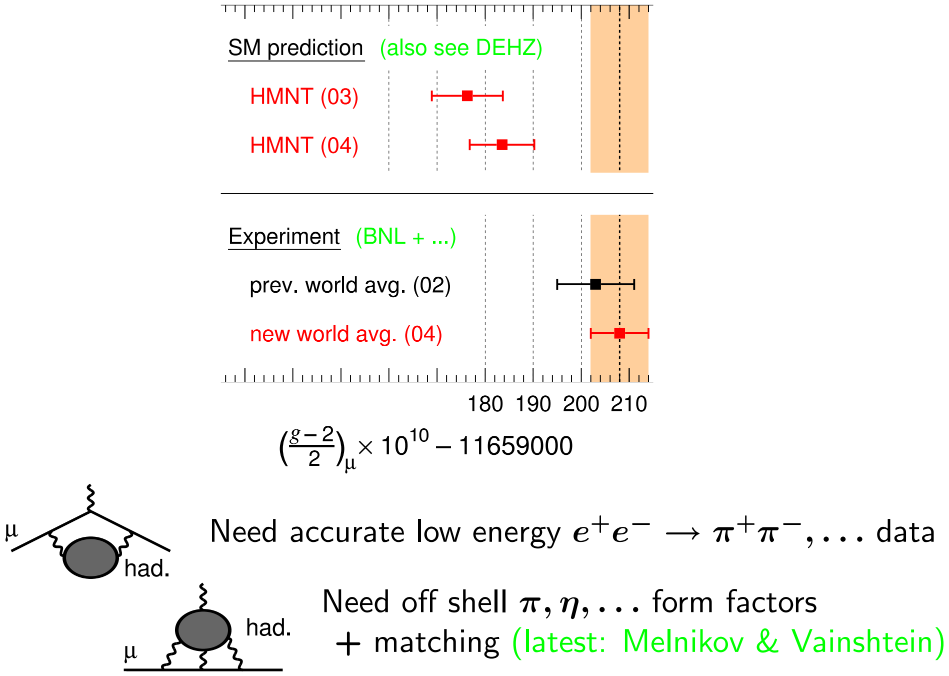

Figure 2. A comparison of the SM model prediction and the experimental value of $g-2$ of the muon. The main uncertainties are associated with the computation of the two diagrams shown.

2 Low energy QCD

The success of the Standard Model has meant that particle physics has been 'theory-led' for the past thirty years or so. The exception is low energy QCD, where we need all the experimental guidance that is possible. The difficulty stems from the large QCD coupling at low scales. Although theoretical techniques in the non-perturbative domain continue to be developed, predictions are still at a very rudimentary stage. The need for experiment in this domain is well illustrated by three examples taken from talks presented at this Workshop.

The first example is the calculation of the anomalous magnetic moment of the muon. Fig. 2, adapted from the talk by Teubner[1], shows the present situation. The error on the SM prediction for this precisely measured *electromagnetic* observable is almost entirely due to the uncertainties in computing the low energy *hadronic* contributions indicated by the two graphs shown at the bottom of the picture.

The second example is from hadron spectroscopy, where the hot topic is pentaquarks. Here, the experimental situation is puzzling. The narrow $B = S = 1$, $\Theta_s(1530)$ state, predicted by the chiral soliton model[a], is seen by several experi-

[a] In the chiral soliton model the lowest-lying exotic baryon multiplet is an antidecuplet, in which Θ_s^+ is the lightest state.

ments, including ZEUS and HERMES at HERA, but not yet, it seems, by H1. On the other hand, H1 report a narrow $B = -C = \pm 1$ state at 3099 MeV, perhaps a bit heavy for a Θ_c pentaquark, which is not seen by ZEUS. The situation was reviewed by Karliner[2], who also presented the postdictive interpretations of these states in terms of the constituent quark model. The chiral soliton model and the constituent quark model may be regarded as complementary interpretations. They have been likened to the droplet and shell models of the nucleus. The results of the dedicated pentaquark experiments should be available at the end of the summer, and are eagerly awaited.

Another example of experiment-led QCD was well illustrated by Wu-Ki Tung's 'trip down memory lane'[3]. He recalled some of the many 'twists and turns' of the input parton distributions that have been needed in the global analyses over the years to keep pace with the continually improving experimental measurements of DIS and related data. We rely on experiment to determine these input distributions.

3 Deep Inelastic Scattering

From a historical perspective, deep inelastic scattering, and its (Bjorken) scaling interpretation, was decisive in the identification of the quarks of hadron spectroscopy as physical entities. Moreover DIS was crucial for the discovery of asymptotic freedom and the emergence of QCD. A classic prediction of QCD is the logarithmic scaling violations of the proton structure function F_2. Wilczek, one of the discovers of QCD, has recalled the near-ridicule with which this prediction was first met. He was challenged by a famous experimentalist: *'You expect us to measure logarithms ? Not in your lifetime young man!'* Yet in a few years these logarithmic scaling violations were seen in fixed-target experiments. Now, today, we have beautiful plots showing data of amazing precision for the structure function F_2 versus Q^2, for different values of x, over a vast kinematic domain, which the HERA experiments have extended by two orders of magnitude, see Fig. 3.

These, and related, measurements are the essential ingredients for determining the partonic structure of the proton, see Fig. 3. Perhaps the main surprise, to emerge from these global parton analyses, is the valence-like structure of the gluon density at low scales. This feature appears to be present in all post-HERA global analyses, that is from 1994 onwards.

Fig. 4 shows a compilation of the values of $\alpha_s(M_Z^2)$ obtained in the various recent analyses of DIS data. At first sight they appear to be remarkably consistent considering the very different selections of data that are fitted. But all analyses include the BCDMS structure function measurements, which are pivotal in the determination of α_s.

Fig. 5 shows the physical phenomena we expect to be appropriate in various regions of the $\ln Q^2$-$\ln(1/x)$ kinematic plane. Overlaid is a line indicating the reach of the HERA experiments. Of course the position of this line is well known, see Fig. 3. However the positions of the various domains relative to this line are not well known – and have been the subject of much debate at this Workshop. Certainly HERA has opened up the small x domain, and allows us to pose the following questions.

Fixed target DIS ep, ed, νN; Drell-Yan, W asymmetry;
Tevatron jets; HERA ep
global DGLAP parton analyses CTEQ, MRST
analyses to selected data sets Botje, Alekhin, ZEUS, H1…

Expect small x processes to be driven by the gluon.

Surprise at v.low scales appear to be dominated by by singlet sea quarks valence-like or -ve gluon !

Sea quarks & gluons not (perturbatively) connected.

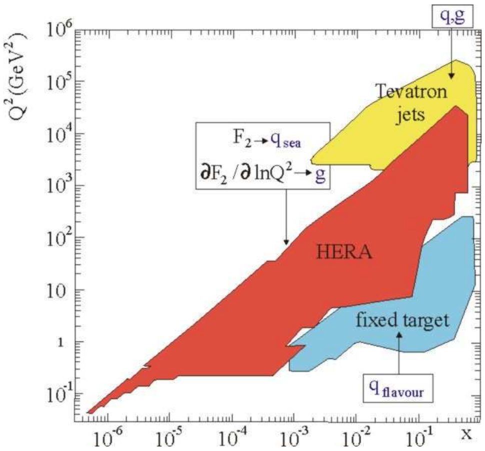

Figure 3. Data used in parton analyses. The plot shows the x, Q^2 kinematic regions covered by the DIS and Tevatron jet data, together with the partons that are constrained by the data.

α_s from DIS

	$\Delta\chi^2$	$\alpha_S(M_Z^2)$ ± expt ± theory ± model
NLO		
CTEQ6	100	0.1165 ± 0.0065
ZEUS	50	0.1166 ± 0.0049 ± 0.0018
MRST03	5	0.1165 ± 0.002 ± 0.003
H1	1	0.115 ± 0.0017 ± $0.005^{+0.0009}_{-0.0005}$
Alekhin	1	0.1171 ± 0.0015 ± 0.0033
NNLO		
MRST03	5	0.1153 ± 0.002 ± 0.003
Alekhin	1	0.1143 ± 0.0014 ± 0.0009

Remarkably consistent, considering v.different selection of data fitted –
but then all include the crucial BCDMS F_2 data

Figure 4. The values of $\alpha_s(M_Z^2)$ found in most recent parton analyses. The experimental error reflects the tolerance $\Delta\chi^2$.

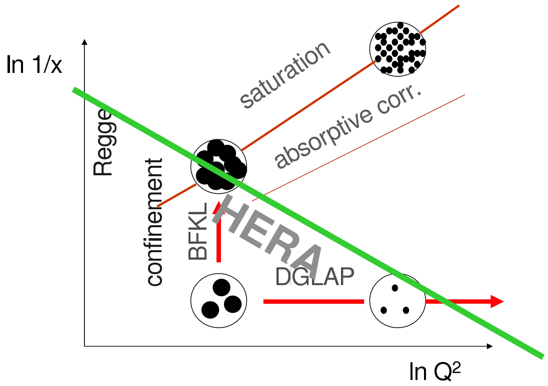

Figure 5. Physical phenomena in various regions of the ln $1/x$ - ln Q^2 plane, compared to the kinematic reach of the HERA experiments.

- How large is the domain where pure DGLAP is valid ?
- Are BFKL (log $1/x$) effects evident ?
- Is there any evidence of absorptive corrections, or even parton saturation ?
- The HERA experiments observe *diffractive* DIS (at $\sim 10\%$ of DIS) – what role does it play in the parton analyses ?
- What new measurements would we like the HERA experiments to perform now ?

We attempt to address these questions below.

4 The gluon distribution

As mentioned above, one of the discoveries of HERA is the unexpected behaviour of the gluon – the analyses of the small x data surprisingly reveal a valence-like gluon at low scales, whereas it is the sea quarks that grow with decreasing x. Moreover, the gluon is not well determined – for example, at $Q^2 = 100$ GeV^2 there is at least a 10% uncertainty arising just from the statistical and systematic errors on the data, becoming much greater at small and large x, see Fig. 6. Discussions at the Workshop concentrated on the equally, and perhaps more, important theoretical uncertainties on the determinations of the partons. These are listed in Fig. 7.

One source of uncertainty has been considerably reduced, since the complete NNLO splitting functions have been presented, for the first time, at this Workshop by Moch, Vermaseren and Vogt[4]. Their exact results lie in the middle of the approximate bounds they had previously determined, so the existing NNLO global analyses based on these bounds will be valid. As of DIS 2004, we have entered the NNLO era. Of course, this is for evolution within a pure DGLAP framework, which must break down at sufficiently low x and low Q^2. Much research has been devoted to quantifying the size of the additional ln$1/x$ effects, notably by the Firenze group,

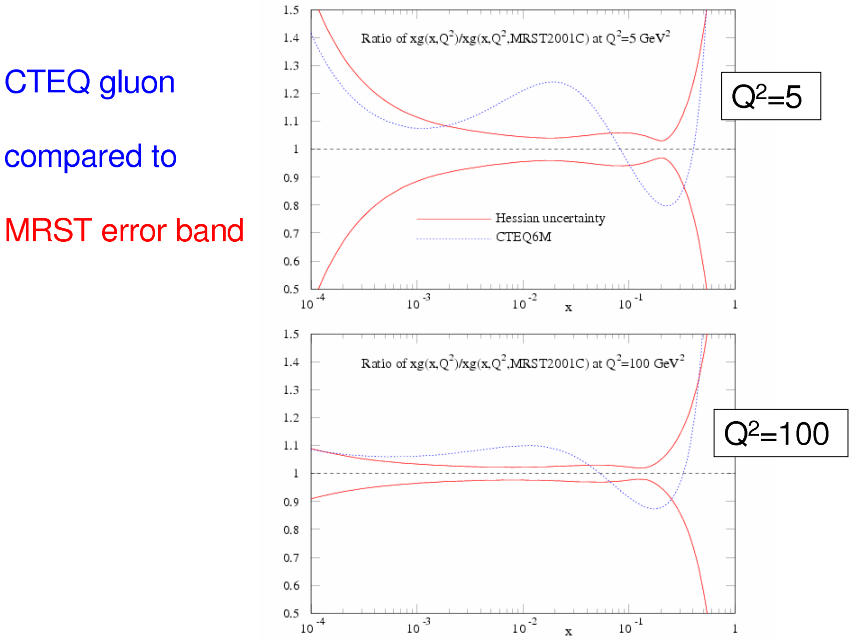

Figure 6. The uncertainty in the gluon distribution arising from the statistical and systematic errors of the data fitted in the MRST parton analysis, compared to the gluon obtained in the CTEQ analysis. The difference is quite sizeable, and the CTEQ value sometimes lies well outside the MRST error corridor (and vice versa). This is not surprising, as there are many other uncertainties in these analyses, see Fig. 7.

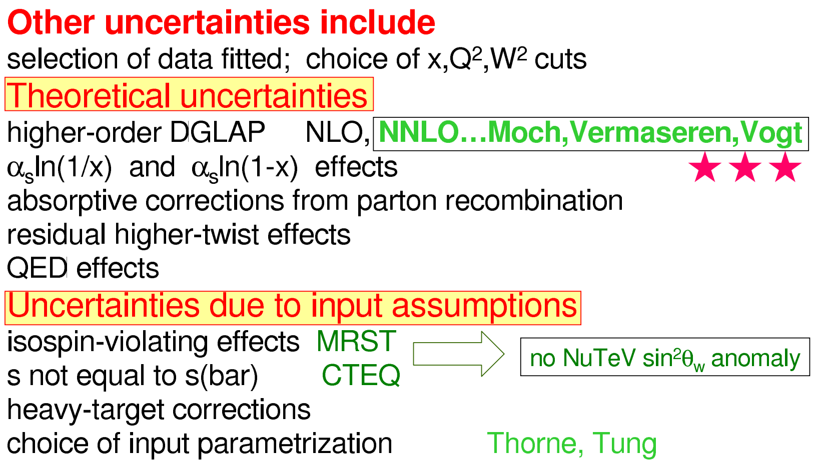

Figure 7. Uncertainties in parton analyses, besides the experimental errors on the data that are fitted. Looking at some of the more detailed assumptions used in parton analyses, it appears that the NuTeV $\sin^2\theta_W$ anomaly may not exist. If we allow for strange quarks with $s \neq \bar{s}$, for isospin violating effects and for QED contributions, then each may significantly reduce the anomaly.

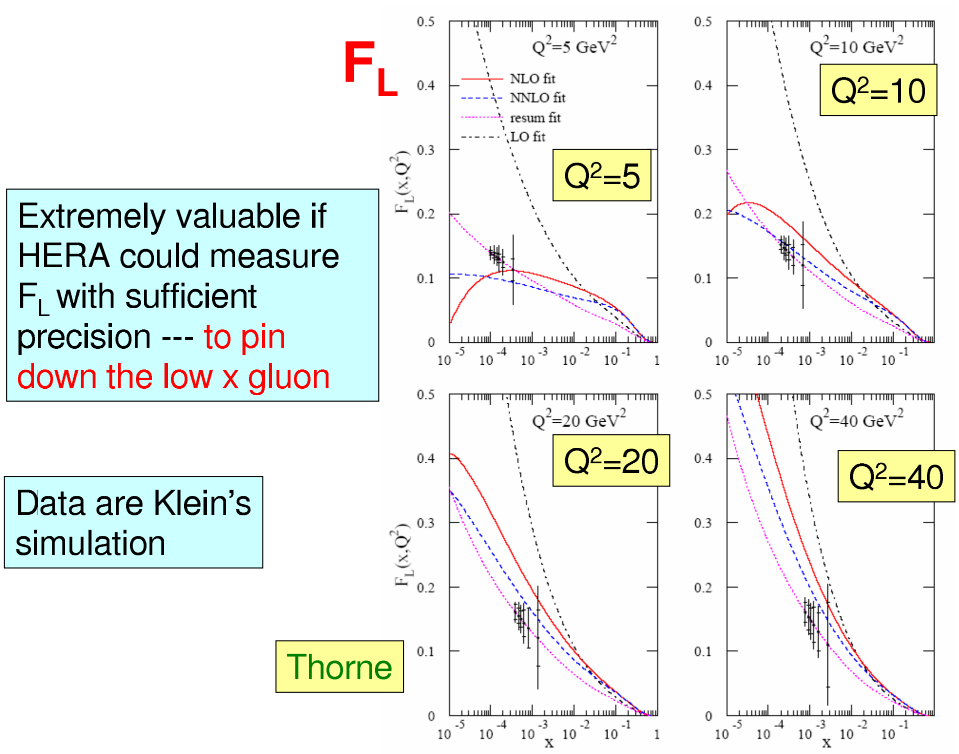

Figure 8. Various predictions for the behaviour of F_L versus x[6]. The simulated data which are superimposed on one of the curves have experimental errors that could be achieved by running HERA at four different proton energies – 400, 465, 575 and 920 GeV[7].

see[5], and also [6]. The results of these investigations indicate that the additional $\ln 1/x$ effects are not large in the HERA kinematic domain.

The identification and the study of New Physics at the LHC, Tevatron or HERA, is likely to require precise Standard Model predictions, which in turn rely on accurately known partons. Recall that the poorly known gluon distribution is at the heart of parton analyses. At present the gluon is mainly determined by the scaling violations of F_2, by F_2 charm and by Tevatron (and HERA) jet data. At the Workshop, it became clear that it is crucial to measure the longitudinal structure function F_L. It is a direct, 'orthogonal', measure of the gluon. We were presented with simulations which showed how running HERA at four different proton energies, with a total luminosity of about 50pb^{-1}, would have a decisive effect on determining the gluon, see Fig. 8.

5 Saturation?

There was much discussion of parton saturation. It was described how the alternative non-linear equations, which describe saturation, are in fact equivalent; simply

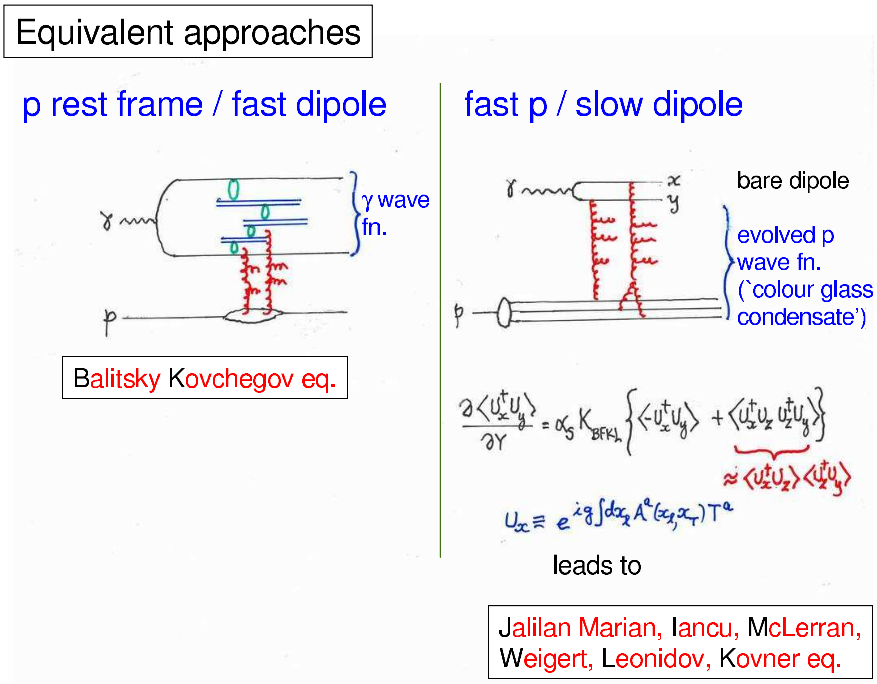

Figure 9. Schematic diagrams which give a glimpse of why the BK and JIMWLK equations are equivalent approaches to saturation – simply viewing the parton recombination process from different Lorentz frames. I thank E. Iancu for educational discussions.

viewing the parton recombination process from different Lorentz frames, see Fig. 9. Despite the theoretical activity, the consensus of the Workshop was that there was no evidence of saturation in the perturbative domain of the HERA data. This does not mean that absorption corrections – signaling the onset of saturation – are negligible. Indeed the recent diffractive DIS data from HERA allow an estimate of such effects, and hence of their influence on global parton analyses, as we will discuss in a moment.

It is informative to discuss saturation in the context of the phenomenological saturation model proposed by Golec-Biernat and Wüsthoff. It is based on the dipole formulation of DIS (and diffractive DIS), which is perfectly general, see Fig. 10. By parametrising the dipole cross section, $\hat{\sigma}$, in a saturation form, GBW were able to describe the DIS data, and also the diffractive DIS (DDIS) data. The original fit to F_2 is reproduced in Fig. 11. An important point to notice is that the fits require the introduction of a quark mass $m_q = 140$ MeV in the wave function ψ specifying the $q\bar{q}$ component of the photon.

The phenomena which we call saturation means $\hat{\sigma}$ stops growing with the decrease of x or Q^2. Such an effect can occur for two reasons. The DIS cross section is proportional to the number of dipoles and to the size of each dipole. By decreasing Q^2 we enlarge the dipole size up to a limit specified by the forces of confinement. This effect is clearly seen in the data. Alternatively, increasing the energy, that is

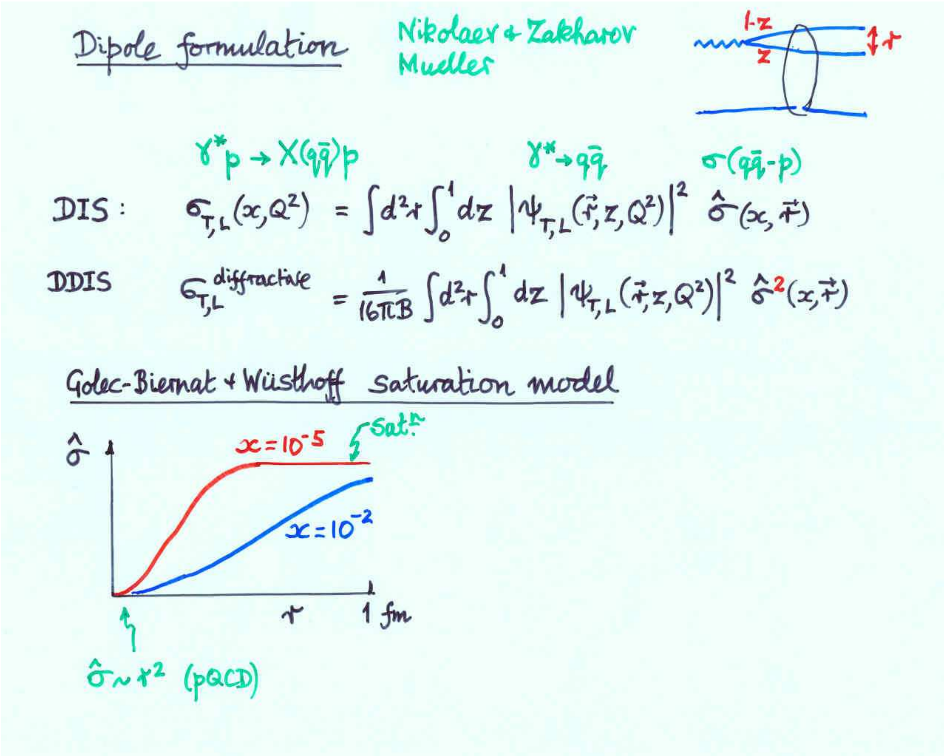

Figure 10. The dipole formulation of DIS and diffractive DIS (DDIS), where $\hat{\sigma}$ is the cross section for the scattering of the $q\bar{q}$ dipole on the proton. In the Golec-Biernat, Wüsthoff model[8], $\hat{\sigma}$ is parametrised in a saturation-type form, which has a behaviour typical of the sketch shown.

$1/x$, enlarges the number of dipoles of a given size. The dipole density is eventually limited by unitarity (the Froissart bound) and at sufficiently high energy the cross section saturates. If this last effect is significant we would expect the saturation boundary $Q_s(x)$ to grow with energy. The data do not exclude such a tendency, though it appears to be very weak, see Fig. 11. Moreover confinement and charm mass effects complicate the interpretation of the data. In the GBW model confinement is mimicked by introducing a quark mass in the $q\bar{q}$ wave function; the mass is typical of the confinement radius, rather than a constituent quark mass. Thus we may ask if the behaviour of the data is more due to confinement rather than the effect of parton saturation. Also, there exist other satisfactory dipole fits of these data which do not contain saturation explicitly.

6 Diffractive DIS

Fig. 12 shows the most recent diffractive DIS data from HERA. Although these data are preliminary, it is evident that the precision has improved significantly. Agreement between the ZEUS and H1 data sets is better than before. They still

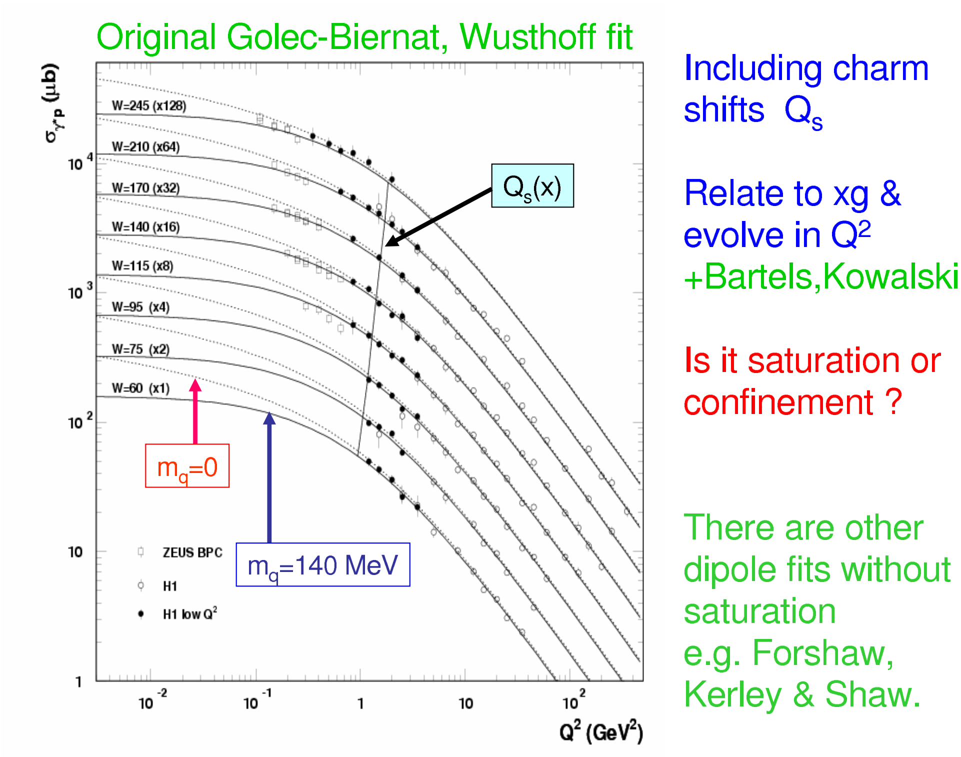

Figure 11. The fit of the dipole saturation model to F_2.

have somewhat different x_P behaviour, but both may be described simultaneously with a reasonable χ^2, see the curves in Fig. 12. With their new data, H1 assume naive Regge factorization and extract the parton densities of the Pomeron. These are consistent with their earlier fit.

The precision of the data encourage a more QCD-based analysis. The first steps along these lines were taken by BEKW[9], in which the β dependence of the data was described by a QCD-motivated ansatz, see Fig. 13. Very recently the QCD approach has been taken further by MRW[10]. The new description accounts for the fact that the QCD Pomeron is a complicated object consisting of gg (and $q\bar{q}$) pairs of different size. Usually the $q\bar{q}$ component of the QCD Pomeron is neglected, however in the global parton analyses the sea quark density is comparable to the gluon at low x and low Q^2. The MRW fit takes LO QCD expressions for the input parton distributions in the Pomeron, allowing for an important role for the $q\bar{q}$ component. The resulting description of the ZEUS and H1 diffractive data is shown by the curves in Fig. 12.

Moreover this QCD description of the diffractive data, together with the use of the AGK cutting rules, enable us to address the long-standing question – what role do the diffractive DIS data play in the global analyses of the inclusive DIS data?

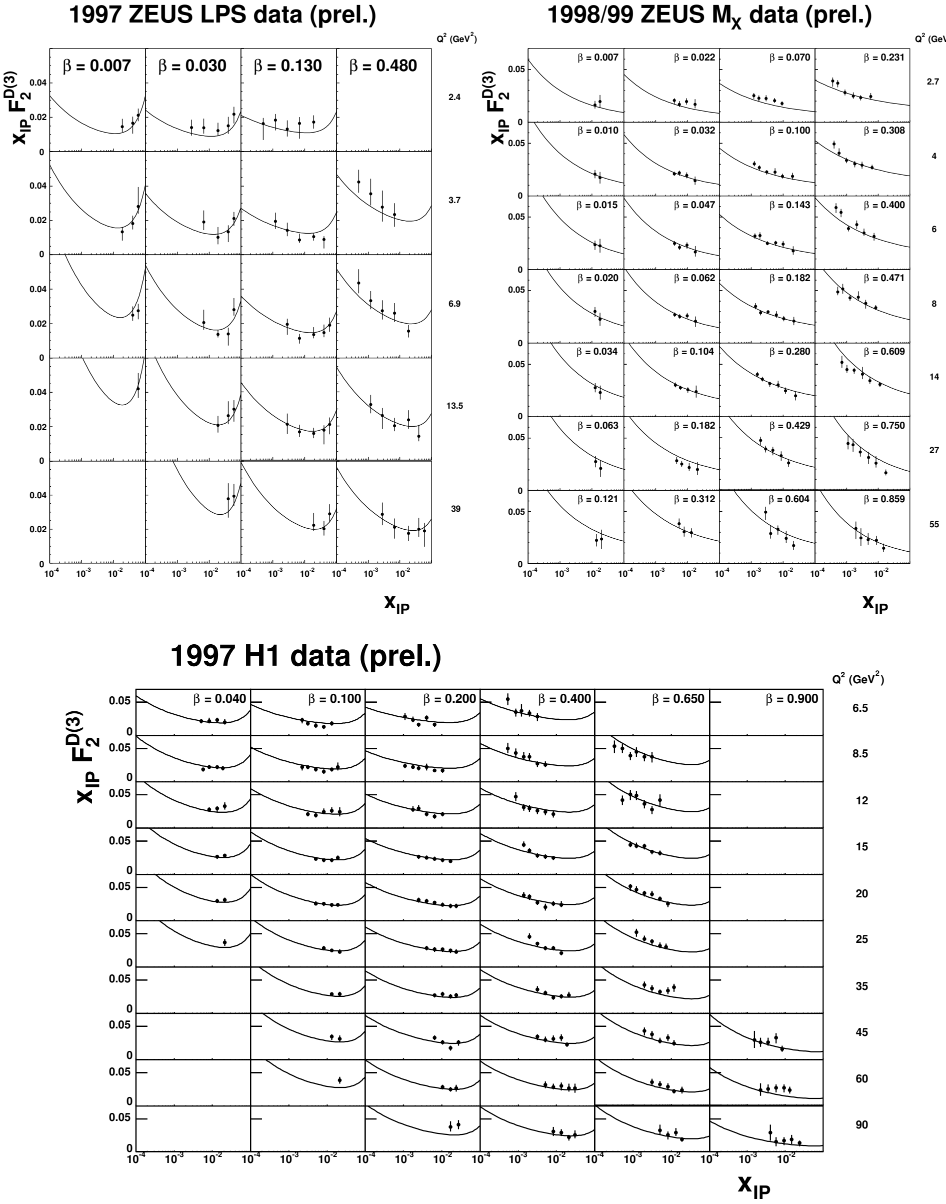

Figure 12. Preliminary ZEUS and H1 data for diffractive DIS. The curves are a fit to all these data, normalised to the ZEUS LPS data: the normalisation factors parameters of $N = 1.56$ and 1.26 found for the ZEUS M_X and H1 data respectively, allow for proton dissociation[10].

Are the DDIS data already included in the input distributions of the DIS analysis or should they be allowed for in the DGLAP evolution? The answer is that they

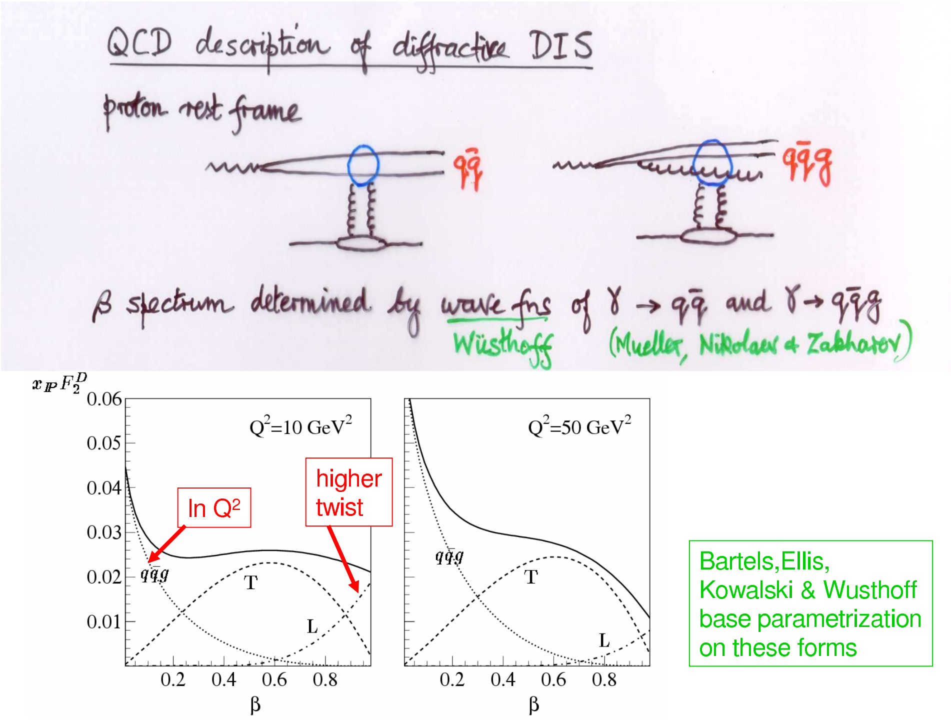

Figure 13. The upper two diagrams show the contributions to diffractive DIS mediated by a quark dipole and an effective gluon dipole interacting with the proton via a perturbative Pomeron composed of two t-channel gluons. The lower plots show how the β spectrum of the diffractive data is made up from these dipole contributions. T and L indicate the $q\bar{q}$ contributions from transversely and longitudinally polarised photons.

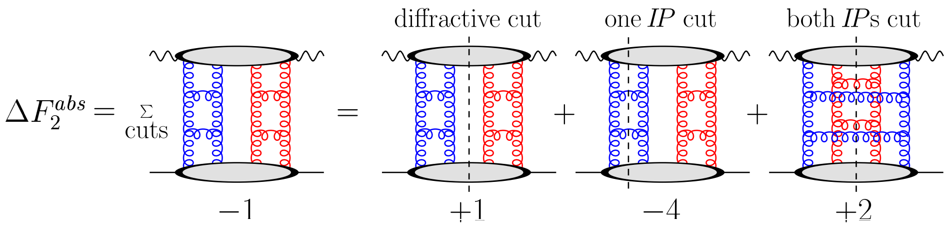

Figure 14. The two-Pomeron exchange contribution to F_2. The equality shows the application of the AGK cutting rules, and the relative magnitudes of the diagrams. All permutations of the two gluon ladders (forming Pomeron exchange) are implied.

occur partially in both. Consider the application of the AGK cutting rules[11] to the absorptive contribution to F_2 that is sketched in Fig. 14. We see from the relative magnitudes of the diagrams that

$$\Delta F_2^{\rm abs}(x_B, Q^2; \mu^2) \;\simeq\; -\,F_2^D(x_B, Q^2; \mu^2) \qquad (1)$$

where $F_2^D(x_B, Q^2; \mu^2)$ is the contribution to the diffractive $F_2^{D(3)}$ (integrated over x_P) which originates from a perturbative component of the Pomeron of size $1/\mu$. Since the equality is valid for each component, μ, of the perturbative Pomeron, we can separate the screening corrections coming from low $\mu < Q_0$ (which are included in the input parametrizations) from the absorptive effects at small distances ($\mu > Q_0$) which occur during the DGLAP evolution embodied in the global analyses of DIS data. This becomes possible because the QCD fit to the diffractive data determines the partonic components of the Pomeron of different size. Thus it is possible to separate the part of the absorptive effect which is hidden in the input distributions in the global inclusive fit, and the part which affects the perturbative evolution[12].

7 Rapidity gap survival factors

In principle the diffractive parton densities obtained from the analysis of DDIS data enable predictions to be made for the cross sections of all 'hard' diffractive processes. However, unlike the conventional parton densities, they are not universal. The rapidity gaps, which characterise diffractive processes, may be populated by secondary particles generated by 'soft' rescattering processes. The survival probability of the rapidity gap, $\hat{S}^2$, depends on the particular hard subprocess. It may be estimated using[13]

$$\hat{S}^2 \;=\; \frac{\int |\mathcal{M}(s,b)|^2 \exp(-\Omega(b)) d^2b}{\int |\mathcal{M}(s,b)|^2 d^2b}, \tag{2}$$

where $\mathcal{M}$ is the amplitude in impact parameter b space of the particular hard subprocess and Ω is the opacity of the interaction of the incoming hadrons; $\Omega/2$ is frequently called the eikonal. The formula has been written for a single-channel eikonal, but usually a multi-channel eikonal is used. Clearly $\hat{S}^2$ depends on the nature of the colour-singlet (Pomeron or W/Z boson or photon) exchange which generates the gap as well as on the distributions of partons inside the proton in impact parameter space.

The CDF measurements of diffractive dijet production with a leading antiproton, at the Tevatron, have provided the classic manifestation of $\hat{S}^2$. The prediction of the cross section, based on factorization in terms of diffractive structure functions obtained from the HERA DDIS data, indicates a large discrepancy with the CDF measurements. The CDF data lie about a factor of 0.1–0.2 below the predictions. This factor is in agreement with the estimates of the survival probability, $\hat{S}^2$, of the rapidity gap of the hadronic process.

At this conference we have seen another interesting manifestation of $\hat{S}^2$. Recent HERA data allow us to study how factorization breaking changes for the diffractive production of dijets as we go from real to virtual photons. A good way to study the breaking due to $\hat{S}^2$ is to take the ratio R of diffractive dijet production to inclusive dijet production. High Q^2 diffractive dijet production, unlike diffractive photoproduction of dijets, is not expected to suffer a suppression due to rescattering. Indeed, in the ideal theoretical limit, it is estimated that[14]

$$R(\text{photoproduction}) \;\simeq\; 0.34\; R(\text{high } Q^2), \tag{3}$$

except at $x_\gamma = 1$, where the ratios are expected to be equal since the 'direct' photon contribution should have very small rescattering corrections. A NLO analysis of the data by Klasen and Kramer[15], along these lines, is in good agreement with preliminary H1 data.

The survival factor $\hat{S}^2$ has relevance to the exclusive diffractive production of 'light' Higgs bosons at the LHC. The process is $pp \to p + H + p$, where the + signs indicate the presence of rapidity gaps. If the two outgoing protons are tagged then the mass of the Higgs can be determined in two independent ways – first, by the missing mass to the tagged protons and, second, by observation of its $b\bar{b}$ decay. A second advantage of this process is that the QCD $b\bar{b}$ background is suppressed by a $J_z = 0$ selection rule. The survival factor for this exclusive process is estimated to be 0.026, and the cross section to be 3 fb at the LHC. For an integrated luminosity of 30 fb^{-1} and a Higgs mass of 120 GeV we expect, after cuts, a handful of events, with a signal-to-background ratio of about 1. Interestingly, for SUSY Higgs bosons, there are regions of parameter space where the conventional signals are considerably suppressed, but where the exclusive diffractive signal is enhanced with a signal-to-background ratio of about 10[16].

8 Final comments

DIS continues to flourish as evidenced by the wealth of information presented in the working groups, and succinctly summarised by the convenors. However, much remains to be learnt – we are just getting to grips with many basic problems. It is inconceivable that HERA will not measure F_L with sufficient precision to determine the gluon. Low energy runs should be done. They will also improve the knowledge of the large x partons. Recall that accurate parton densities are essential to realize the full physics programme of the LHC.

Even forgetting the surprise discovery of exotica, there are many other crucial measurements still to be done. Hopefully time will not run out for HERA while the physics potential of the machine is still coming to its prime.

Last, but not least, Dusan Bruncko and Jozef Ferencei, together with their colleagues from the Slovak HEP Institutes, are to be congratulated in organizing such a fruitful and enjoyable Workshop.

Acknowledgements

The award of a Leverhulme Emeritus Fellowship is gratefully acknowledged. I thank Max Klein, Misha Ryskin, Robert Thorne, Manuella Vincter and Graeme Watt for valuable help.

References

1. T. Teubner, these proceedings.
2. M. Karliner, these proceedings.
3. W.-K. Tung, these proceedings.
4. A. Vogt, these proceedings.

5. G. Salam, these proceedings.
6. R.S. Thorne, these proceedings.
7. M. Klein, these proceedings.
8. K.J. Golec-Biernat and M. Wüsthoff, Phys. Rev. **D59** (1998) 014017.
9. J. Bartels, J. Ellis, H. Kowalski and M. Wüsthoff, Eur. Phys. J. **C7** (1999) 443.
10. A.D. Martin, M.G. Ryskin and G. Watt, hep-ph/0406224.
11. V.A. Abramovsky, V.N. Gribov and O.V. Kancheli, Yad. Fiz. **18** (1973) 595 [Sov. J. Nucl. Phys. **18** (1974) 308];
    J. Bartels and M.G. Ryskin, Z. Phys. **C76** (1997) 241.
12. A.D. Martin, M.G. Ryskin and G. Watt, hep-ph/0406225.
13. E. Gotsman, E. Levin and U. Maor, Phys. Rev. **D60** (1999) 094011;
    V.A. Khoze et al., Eur. Phys. J. **C18** (2000) 167;
    A.B. Kaidalov et al., Eur. Phys. J. **C21** (2001) 521.
14. A.B. Kaidalov et al., Phys. Lett. **B567** (2003) 61.
15. G. Kramer, these proceedings.
16. A.B. Kaidalov et al., Eur. Phys. J. **C33** (2004) 261.